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Energy-efficient food production to reduce global warming and ecodegradation: The use of edible insects

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A B S T R A C T

As the global population continues to rise, and attempts to increase arable land area come in sharp conflict with the necessity to retain forests on one hand and pressures of urbanization on the other, the wave of global food shortage that has hit the world recently is likely to hit us again and again.

The increasing pressure on land is making meat production from macro-livestock less sustainable than ever before. To add to the diminishing pastures and broadening demand-supply gap of food grains are the shortages arising due to the diversion of some of the food crops for biofuel production. There is also an increasing use of fodder for generating biomass energy. The result is that even as the demand for animal protein keeps on rising with the swelling global population, there is every possibility that attempts to meet this demand would face serious crises in the coming years. The adverse impacts of global warming are conspiring to make the situation even worse than it otherwise would have been.

The present review brings home the fact that one of the possible ways to get around this problem is to extend the practice of entomophagy – use of insects as human food. As of now entomophagy is practiced in some regions and some cultures, but, by-and-large, the bulk of global population stay away from it. It is even looked down in several cultures and forbidden in some others. The review brings out the irrationality of omitting edible insects from human diet given the generally higher quality of nutrition they contain as compared to food based on macro-livestock. This aspect, coupled with much lesser consumption of energy and natural resources associated with insect-based protein production, makes entomophagy an option which deserves urgent global attention.

The authors highlight the relatively stronger sustainability of animal protein production by way of insect farming because, pound to pound, the production of insect protein takes much less land and energy than the more widely consumed forms of animal protein. It is estimated that over a thousand insect species are already a part of human diet and the nutrition offered by several of the species matches or surpasses that which is contained in traditional non-vegetarian foods. The paper also deals with the relevance of entomophagy as a potentially more ecologically compatible and sustainable source of animal protein than the red and the white meat on which most of the world presently depends. In the emerging global pattern based on an expanding share of renewable energy sources, entomophagy fits in as a renewable source of food energy for the future.

Contents

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1. Introduction

Anthropoentomophagy – in other words use of insects as food by humans – is an age-old phenomena [1]. By all accounts, which include archeological evidence as well as analysis of fossilized feces [2], mankind has evolved as an antomophagous species [3–5].

With the advent of organized religions, the number of humans who avoided entomophagy began to increase because in some religions the adherers are advised to eat only certain kinds of red or white meats (which all but exclude insects) while in some other religions eating of any form of animal protein is discouraged to prevent animal sacrifice [6,7].

The colonization of Asia, Africa, and the Americas during the few previous centuries as also spread of ethnic Europeans in Australia further eroded entomophagy just as it eroded cultural diversity everywhere in various other ways [8–12].

The impact of globalization and the fascination among a large cross-section of population towards fast-food 'culture' has further weaned away a large number of protein-hungry people of the third world from what till now was a rich and affordable source of animal protein for them – i.e. insects [13,14].

But even as entomophagy is now alien to a large cross-section of global population it is still very much practiced all over the world. Whereas it is the food supplement of the economically backward people in most situations [15–19], it is by no means always 'a poor-man's subsistence' [2,20–22].

In North-Eastern India, South-East Asian countries, and in parts of Australia and Europe, insect species are used in many an elite cuisine [4,6]; for example:

- Wasps, bamboo caterpillars, cricket, and locusts are sold as delicacies in the finest restaurants and food shops in Thailand.
- Annual sales of ant food in china reach $100 million.
- The rice-field grasshopper, called *inago* is a luxury food item in Japan. So are canned wasps, a 65 g can sells for over $10 (₹ 450). Even more expensive are hornets which sell at over $ 20 (₹ 900) for 100 g.
- There is an explosion of tourist interest in the native Australian "bush tucker" foods, which include insects such as wichety grubs (Cossidae), bogong moth, and bardee larva.
- In Mexico upmarket restaurants charge upwards of $ 25 (₹ 1000) per plate of *escamoles* (pupae of an ant species) and *gusanos* (butterfly larvae). When exported to Canda *escamoles* muster a fantastic price of $ 50 (₹ 2500) for a 30 g can (almost two dollar per gram).

2. The superiority of insects as a source of animal protein

The foregoing makes us aware of an important reality: the summary dismissal of entomophagy as something uncouth and unhealthy by the majority of the so-called culturally and/or economically advanced populations betrays more of ignorance and arrogance than culture and sophistication [12].

This reality dawns upon us more sharply when we face the following facts:Insects are *poikilothermic* – in other words insects spend much less amounts of food energy and nutrients than the warm blooded livestock which are the mainstay of non-vegetarian diets [23].Insects are far more efficient in transforming phytomass into zoomass (i.e. plant biomass into animal biomass) than conventional livestock [24]: hence far more animal protein is generated per kilogram of phytomass consumed by insects than by conventional livestock.Insects have much higher fecundity and much faster growth rate: for example each individual produces thousands of offsprings compared to just a few that are produced by conventional livestock. And these offsprings reach adulthood within a matter of days compared to months taken by fawl and years by the rumens. These attributes, besides very good nutritive value, have prompted space scientists to consider use of insects as human food in space travel and habitation [2,21,22]. It is believed that by selecting and incorporating appropriate insect species, the material loops in a space-based agro-ecosystem can be closed and the utilization efficiency of the incoming energy can be improved.A lot of insect species are strict herbivores with much cleaner eating habits than the supposedly healthier and prized choice of the elite: lobster, fawl, pork and even rumen [25]. For example grasshopper is one of the cleanest of animals [26].Insects are the biggest animal group on earth; the immense biodiversity harbored by the class *insecta* is reflected in the well-known fact that this single class has more species than all the species of all other classes of animals combined! Indeed insects constitute as much as 80% of the animal kingdom.

Agriculture has been the single most powerful, persistent, and expanding of human activities that has always caused ecodegradation and which has, by now, almost wore down the earth's ecosystem [27–29]. The damage to biodiversity wrought by agriculture has given rise to the phenomena of 'insect pests' by repeatedly creating situations which favour a few insect species to the elimination of several others. The favoured ones then multiply and are termed as pests. We then spend billions of rupees to control these 'pests'; in turn seriously harming the environment further with pesticides. Even this anthropogenic excess can have a beneficial spin off because many of the insect 'pests' are edible, and are indeed utilized as food in some countries [8,30,31]. For example in Mexico the crop pest *Sphenarium purpurascens* is controlled by capture and use as food. This enables hundreds of families to make a living from this activity. Annual profit for this insect harvest reaches almost $3000 dollars per family and the amount of extracted biomass is close to 100 tonnes [32]. But this potential advantage is wasted because people in most other countries just try to destroy the 'pests' [33].

The supreme irony is that all over the world monies worth billions of rupees are spent every year to save crops that contain no more than 14% of plant protein by killing another food source (insects) that may contain up to 75% of high quality animal protein.

3. We can continue to ignore entomophagy only to our peril

On one hand the rising human population is continuously driving up the demand for food, on the other hand there is concomitant reduction in the availability of land resources to produce this food. Now global warming is threatening to jeopardize the full use of even the available land area. This is increasing the food security gap that has been existing between a smaller fraction of global population residing in developed countries and the majority of world population living in developing countries. Developed nations have higher *per capita* protein consumption than developing nations (about 96 g/person/day), but a much greater proportion (65%) of this is derived from meat. In contrast the protein consumption in developing countries is much lesser (about 56 g/person/day) and a still lesser portion (only 15%) of it is animal protein [11,34]. Livestock production, including feedcrop production, occupies 70% of the world's agricultural land (or 30% of the earth's land), and consumes 77 million tonnes of plant or animal protein to produce just 58 million tonnes of protein for human consumption annually [34]. In addition massive areas of land and other resources are used to generate animal protein for the use of pet animals in developed countries. Given this scenario, it is not wise to ignore the potential of insects as human food any longer, especially to provide the badly needed protein for the world's hungry multitudes. The importance of promoting antomophagy is further highlighted by the fact that one in every six habitants of the 6 billion people on the planet earth dies from hunger and malnutrition [35].

Table 1
B-Vitamins in 100 g servings of chicken and beans dishes in comparison to the contents of some insects.

	Thiamine	Riboflavin	Niacin
Daily human requirement	1.5 mg	1.7 mg	20 mg
Fraction met by roasted chicken	5.4%	–	45%
Fraction met by backed beans	10.8%	–	3%
Fraction met by termites	8.7%	67.4%	47.7%
Fraction met by silkmoth larvae	224.7%	112.2%	26%
Fraction met by palm weevil	201.3%	131.7%	38.9%

Adapted from Ref. [36].

4. Potential of insects

Insects are a source of high-quality protein, lipids, carbohydrates and certain vitamins [36]. As many as 1500–2000 species of insects and other invertebrates have been consumed by 3000 ethnic groups across 124 countries in Asia, Australia, Europe, and America [42–44], and there is evidence that shift from entomphagy to 'modern' foods in some regions was accompanied by a general deterioration of the concerned people's health [30].

The mass production of insects also has a great potential to provide animal proteins for human consumption indirectly as livestock feed. This route to macro-livestock production would reduce energy requirements, consequently casting a much smaller environmental footprint, especially if closed systems can be developed at the village or farm level [34].

5. Nutritive value of insects

Based on a study on the nutritive value of 8 insect species commonly eaten in Manipur, India, Gopi and Prasad [37] have concluded that insects represent the cheapest source of animal protein in that region and that their consumption should be encouraged because many of the people cannot afford fish or other meat.

Ramos-Elorduy and Pino [38] calculated the energy values of 94 of the insect species used as food. They found that of the 94 insect species analyzed, 50% had a higher caloric value than soybeans; 87% were superior to maize; 63% were superior to beef, and 70% were better than fish, lentils, and beans. Only 9 of the species analyzed contained less than 30% protein.

DeFoliart [39] has compiled the gist of all the work published till that time on the nutritive values of insects. These accounts, and subsequent studies [8,36,40] reveal that the level of proteins and fats in the insect species is generally high, above those of traditional sources of protein such as meat, dairy products and some seeds. For example, mean values in protein percentages of insects in their immature stages, adult stages and those of the more commonly used food sources have been found to be 36, 38 and 19%, respectively. The highest registered values for proteins for those three groups were 72, 69 and 65% and the mean values for fats were 31, 22 and 14% [41]. Most of the larval stages, particularly those of the Coleoptera and Lepidoptera orders, present a high level of fat [8].

Besides the high *amount* of proteins that insects can provide, several investigations have made evident their high *quality* in a great variety of species [39]. In a nutritional sense, the phrase 'a protein of high quality' implies that it contains different types of amino acids in adequate proportions and that it is highly digestible by the organisms that consume it. Minerals and vitamins are also present in insect-based foods at a significant level [8,40].

As mentioned earlier, rearing of insects provides a much more efficient route to the conversion of consumed matter into accumulated biomass than is possible with macro-livestock. The same efficiency is attained vis a vis transport of nutrients, and several investigations have shown that insects have a higher efficiency of matter assimilation than macro-livestock; more than 10 times more plant nutrients are needed in order to produce one kilogram of meat than one kilogram of insect zoomass. Hence production of insect-based food causes much less strain on ecosystem services than macro-livestock based food [45,46].

Table 2
Protein and iron in 100 g servings of beef and of two insects.

Food	Protein, g	Iron, mg
Beef (broiled)	22.3	2.9
Silkmoth larvae (boiled)	28.2	35.5
Grasshoppers (fried)	61.1	–

Adapted from Ref. [36].

Tables 1 and 2 provide illustrative examples of the nutritive value of insect-based foodstuff in comparison with macro-livestock-based foodstuff.

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